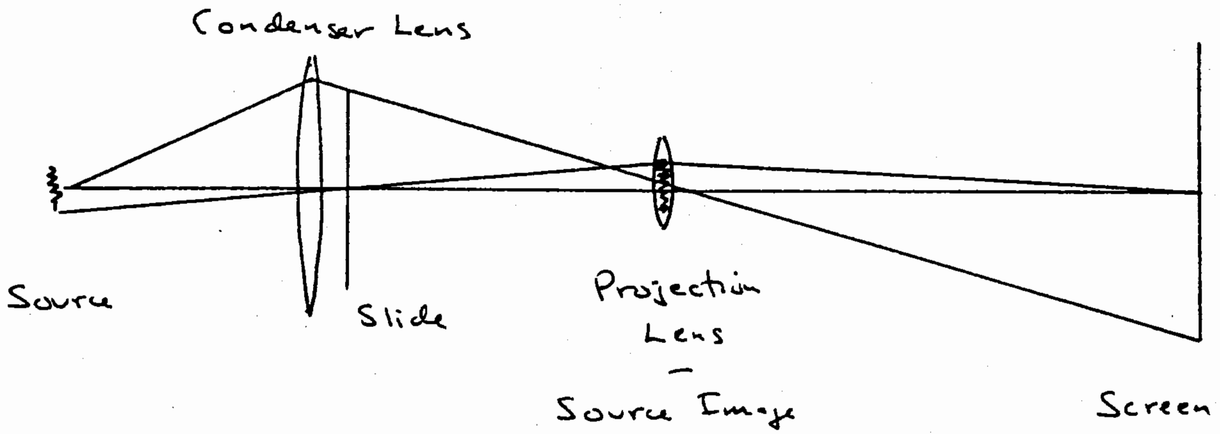
Name Solutions

Closed book; closed notes. Equation sheets are attached and can be removed.
Use the back sides if required. The time limit is 2 hours.
Do not use any pre-stored information or programs in your calculator.
Note any assumptions you make in solving the problems.
Show your work. Present it in a neat and logical fashion.

Thanks for all your efforts this semester. Have a great holiday!!

1) (10 points) Sketch the basic layout of a slide projector showing the important features of a specular illumination system (a projection condenser system).



- Projection Lens images slide to screen
- Condenser Lens images source to projection lens
- Projection Lens size determined by source image
- Condenser Lens size determined by slide
- Each point on the slide is illuminated by the entire source

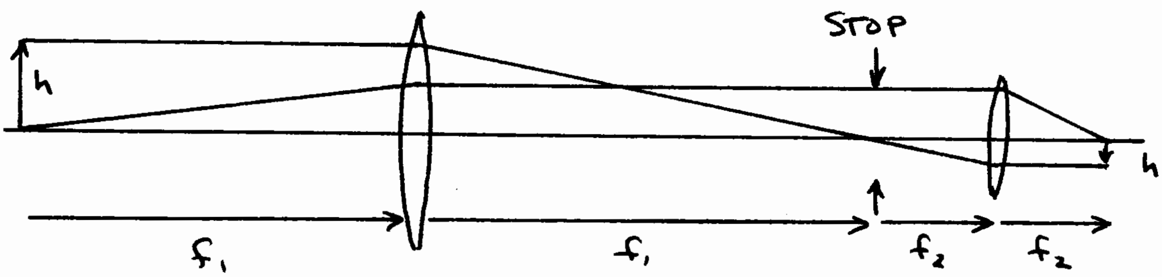
Could be added:

- Concave Cold Mirror or Faceted Mirror

2) (15 points) Design a doubly telecentric system using two thin lenses (in air). The overall object-to-image distance is required to be 200 mm, and the image size is one third the object size. The object and image must both be real. The image-space working F-number is f/5.

Determine the focal lengths, lens separation, object and image positions, stop location and stop size. The lens element diameters are not required.

- The system must be afocal with the stop at the common focal point of the two lenses (F_1', F_2).
- There are many possible object/image location combinations, but the obvious solution places the object at F_1 of the first lens and the image at F_2' of the second lens.



$$\text{Seperation} = 2f_1 + 2f_2 = 200 \text{ mm}$$

$$m = h'/h = -f_2/f_1 = -1/3 \qquad f_1 = 3f_2$$

$$\underline{f_1 = 75 \text{ mm}} \qquad \underline{f_2 = 25 \text{ mm}}$$

Stop at the common focal point.

- Since the marginal ray is parallel to the axis between the lenses, the stop size equals the marginal ray height at the second lens:

$$f/\#_w = f_2/D_2 = 5 \qquad \underline{D_2 = f_2/5 = 5 \text{ mm} = D_{STOP}}$$

3) (15 points) An achromatic prism provides deviation without dispersion. On the other hand, a *direct vision prism* produces dispersion without deviation.

Given two glasses (n_{d1} and ν_1; n_{d2} and ν_2), design a *direct vision prism* with a net dispersion of Δ (i.e. derive the equations for the two prism angles α_1 and α_2).

$$\delta = \delta_1 + \delta_2 = 0$$

$$\delta_2 = -\delta_1$$

$$\delta_1 = (n_{d_1} - 1)(-\alpha_1)$$

$$\delta_2 = (n_{d_2} - 1)(-\alpha_2)$$

$$\Delta = \Delta_1 + \Delta_2$$

$$\Delta_1 = \frac{\delta_1}{\nu_1}$$

$$\Delta_2 = \frac{\delta_2}{\nu_2}$$

$$\Delta = \frac{\delta_1}{\nu_1} + \frac{\delta_2}{\nu_2}$$

$$\Delta = \frac{\delta_1}{\nu_1} - \frac{\delta_1}{\nu_2} = -\left(\frac{\nu_1 - \nu_2}{\nu_1 \nu_2}\right)\delta_1$$

$$\Delta = \left(\frac{\nu_1 - \nu_2}{\nu_1 \nu_2}\right)(n_{d_1} - 1)\alpha_1$$

$$\frac{\alpha_1}{\Delta} = \left(\frac{\nu_1 \nu_2}{\nu_1 - \nu_2}\right)\frac{1}{(n_{d_1} - 1)}$$

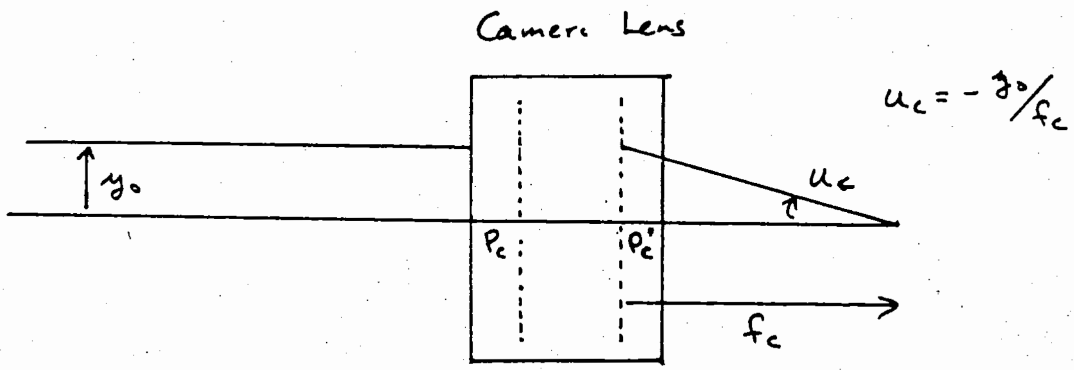
$$\frac{\alpha_2}{\Delta} = -\left(\frac{\nu_1 \nu_2}{\nu_1 - \nu_2}\right)\frac{1}{(n_{d_2} - 1)}$$

4) (15 points) An afocal adapter can be used to change the field of view seen by the detector/film in a camera with a given camera lens. A Galilean or reverse-Galilean telescope is simply placed in front of the camera lens to change the FOV. The afocal adapter is specified by its magnifying power MP, and this use of MP is the same as for a visual telescope.

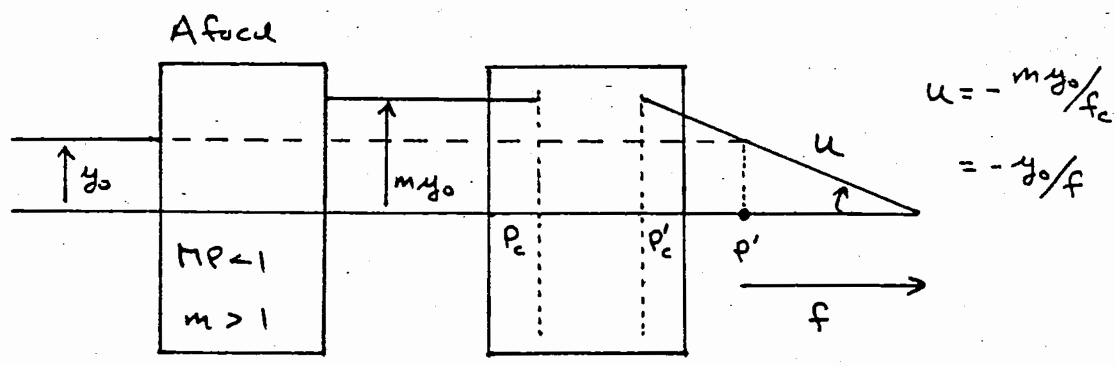
a) If the focal length of the original camera lens is f_C, what is the focal length of the combination of the afocal adapter and the camera lens? You are required to provide a derivation of this result. Hint: Sketch the marginal ray path through the system with and without the adapter and use the definition of focal length (assume an object at infinity).

Show the marginal ray $\quad MP = 1/m$

Without



With



The marginal ray angle in image space increases by $1/MP = m$

$$u = -y_o/f = -my_o/f_c$$

$$f = f_c/m = MP \cdot f_c$$

b) For a wide-angle application (increasing the FOV), should the MP be >1 or <1?

Wide Angle: MP < 1

(Reverse Galilean)

5) (5 points) A field lens is added to a Keplerian telescope. What is the effect of the field lens on each of the following?

a) MP No Change

b) Eye Relief Reduced

c) Exit Pupil Diameter No Change

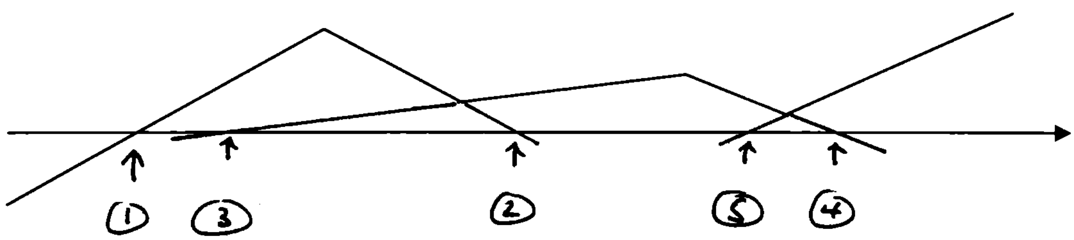
d) Field of View Increased

e) Telescope Length No Change

6) (15 points) The figure below shows the path of the *chief ray* through an optical system comprised of four thin lenses in air. Identify the pupil location in each optical space. Which of these pupils has the largest diameter and why?

The pupils are located where the chief ray in each optical space crosses the axis. This intersection may be in a virtual section of the optical space.

① = EP = Stop ⑤ = XP



For the pupil diameters, use the Lagrange Invariant:

$$\mathcal{H} = n\bar{u}y - nu\bar{y}$$

At a pupil, $\bar{y} = 0$

$$\mathcal{H} = n\bar{u}y \quad \text{or} \quad y = \text{Pupil Radius} = \frac{\mathcal{H}}{n\bar{u}}$$

Therefore, the largest pupil will occur when the chief ray angle $\bar{u}$ is the smallest $(n = 1)$

The smallest $\bar{u}$ and largest pupil is ③

Could also be done by using the pupil magnification:

$$m_p = \frac{\bar{\omega}}{\bar{\omega}'}$$

7) (10 points) Design a thin-lens Petzval objective with the following specifications:
Separation of the two elements = 50 mm
Focal length = 100 mm
Back focal distance = 75 mm

$f = 100$ mm

$BFD = 75$ mm

$\phi = 1/f = .01/\text{mm}$

$t = 50$ mm

$BFD = d' + f_R' = d' + f$

$d' = -25$ mm

$d' = -\dfrac{\phi_1}{\phi} t = -\dfrac{\phi_1}{.01} 50 = -25$

$\phi_1 = .005/\text{mm}$

$\underline{f_1 = 200 \text{ mm}}$

$\phi = \phi_1 + \phi_2 - \phi_1 \phi_2 t = .01/\text{mm}$

$\phi_2 = .00667/\text{mm}$

$\underline{f_2 = 150 \text{ mm}}$

P' is located between the two lenses.

8) (15 points) A catadioptric system uses both reflection and refraction to achieve its focal power. A solid catadioptric system (a solid-cat) can be produced by coating portions of the front and rear surfaces of a lens so that there are transmissive and reflective zones on each surface. In this system, both surfaces have the same radius of curvature.

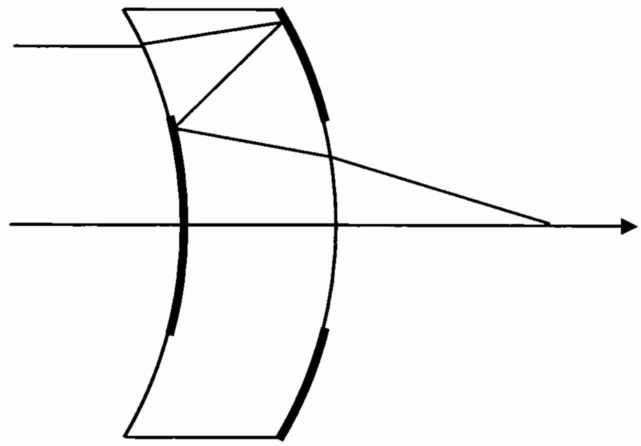
R1 = R2 = -100 mm

t = 30

n = 1.5

The system is in air

$C_1 = C_2 = -.01$



Use a paraxial raytrace to determine the back focal distance and the system focal length.

		Front	Rear	Front	Rear	F'	
Surface	0	1	2	3	4	5	6
C		-.01	-.01	-.01	-.01	–	
t	-∞	30	-30	30	BFD		
n	1.0	1.5	-1.5	1.5	1.0		
−ϕ		.005	-.03	.03	-.005	–	
t/n	-∞	20	20	20	22.82		
Marginal Ray							
y	1	1	1.10	.540	.304	0	
nu	0	.005	-.028	-.0118	-.01332		
u		.00333	.01867	-.00787			
y							
nu							
u							

BFD = 22.82 mm

$\phi = -\omega'/y_1 = .01332/\text{mm}$

f = 75.08 mm